Improving Reliability of High Power Quasi-CW Laser Diode Arrays Operating in Long Pulse Mode

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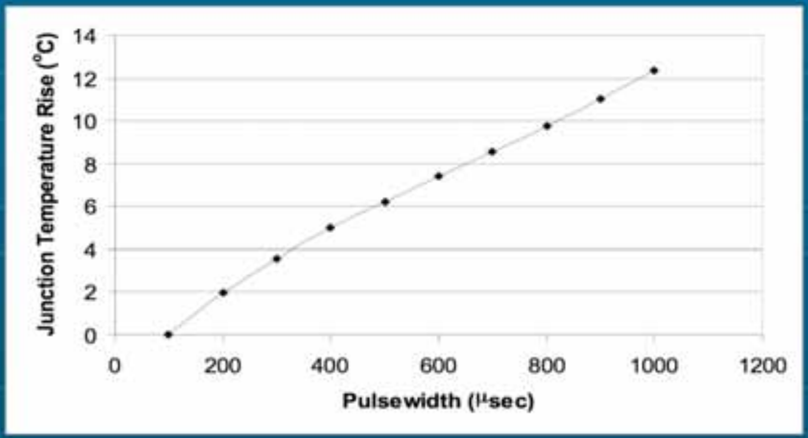
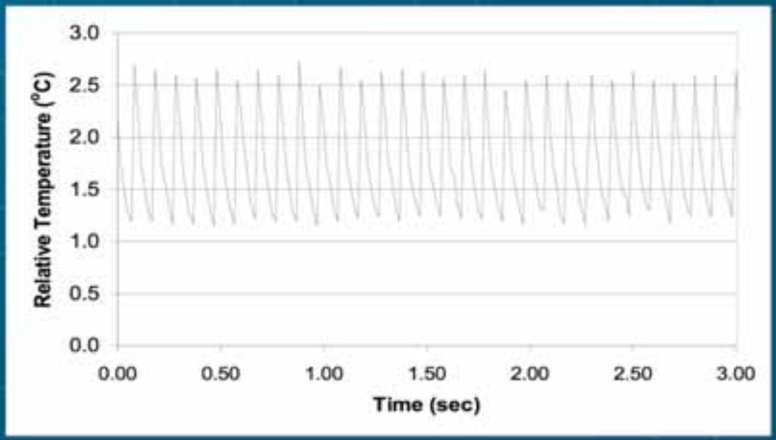
Background

- 2-micron Thulium/Holmium-based solid state lasers require long pump pulse duration of about 1 msec.
- Operating in long pulse regime limits the lifetime of laser diode arrays due to excessive heating of the active regions and drastic pulse-to-pulse thermal cycling.



Junction temperature rise versus pulsewidth for a 6-bar laser diode array operating at 78 A.

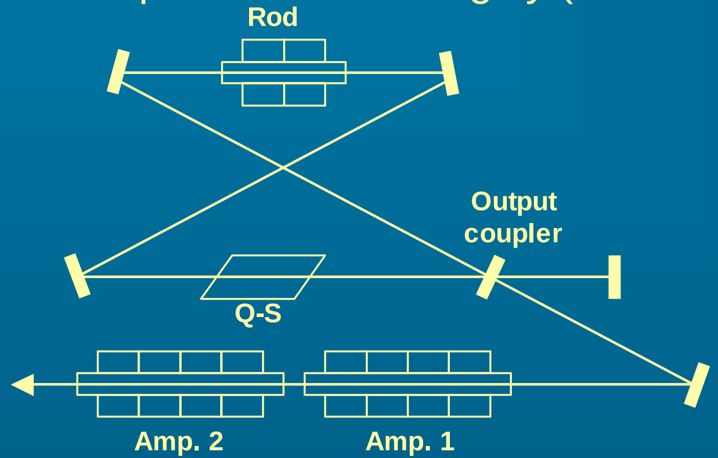


Temperature of the face of an array generating 1 msec pulses at 10 Hz measured by an infrared camera.

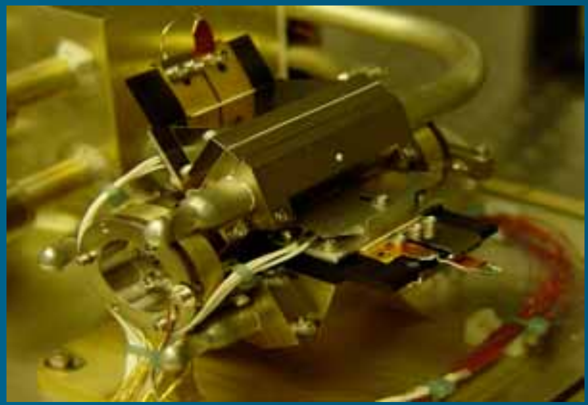
2-micron Solid state Laser for Space Applications

- Conductively-cooled 2-micron Th/Ho Laser is the primary candidate for global wind measurements from space using Coherent Doppler Lidar technique

General design of 2-micron MOPA laser transmitter
Being developed at NASA Langley (Dr. Jirong Yu)



Conductively-cooled Oscillator head



Lidar Instruments	Output Pulse Energy	No. of Bars	Peak Power/bar	Pump Pulsewidth
2-micron Coherent Lidar	250 mJ	108	100 W	1 msec
	1.0 J	216	100 W	1 msec
CALIPSO	110 mJ	192	50 W	170 μsec
GLAS	110 mJ	54	65-85 W	200 μsec

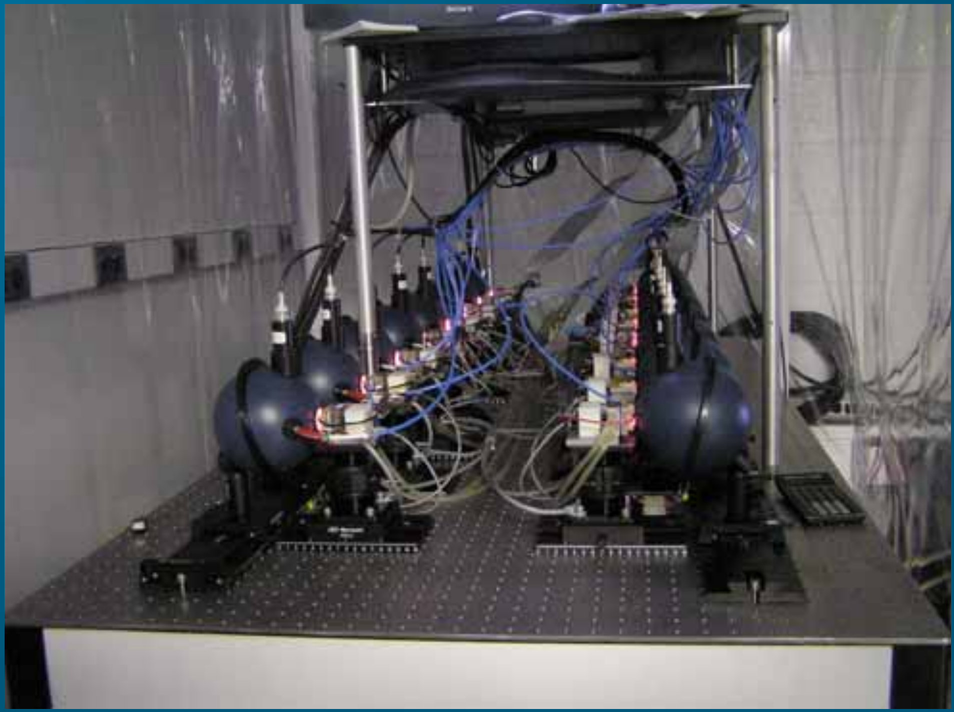
Characterization and Lifetime Testing of 792 nm LDAs

- Characterized over 200 “6-bar Arrays” rated at 600W from 4 major suppliers
- Began lifetime testing of Standard “A” and “G” packages in February 2004
- LDAs have been tested at full rated power and expected operational parameters for a “*space-based 2-micron coherent lidar* “ system
  - Drive current 100 A
  - Rep. rate 12 Hz
  - Pulse duration 1 msec
  - Operating temp. 25 deg. C

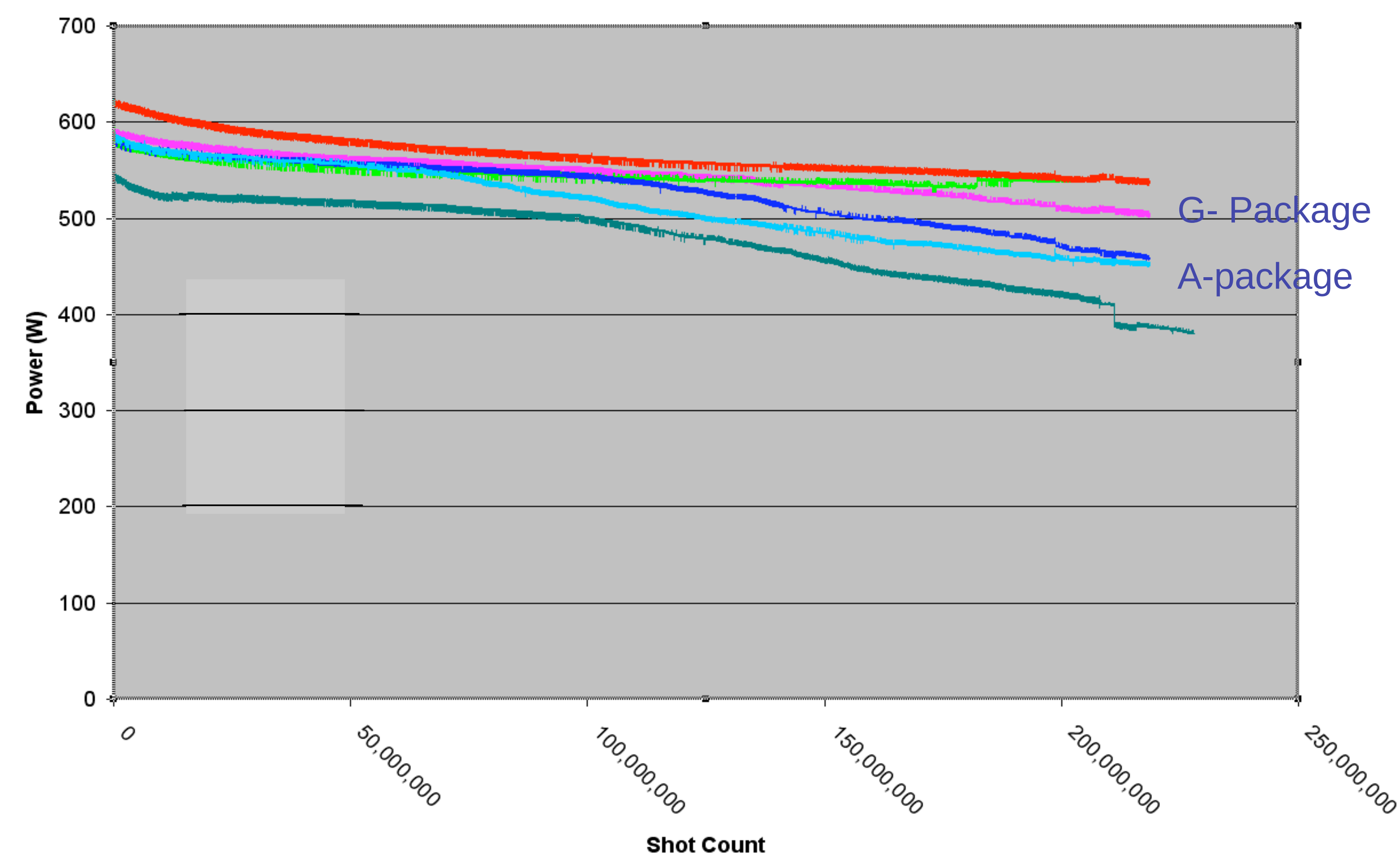
No elevated temperature or higher PRF lifetime acceleration

Laser Diode Lifetime Test Facility

- Measures 16 LD Arrays Simultaneously - 24/7 operation.
- Fully Automated
  - Control and Operation
  - Data Acquisition and Archive (Performance and all relevant environmental parameters)
  - Diagnosis and Alert
  - PC/Web-based

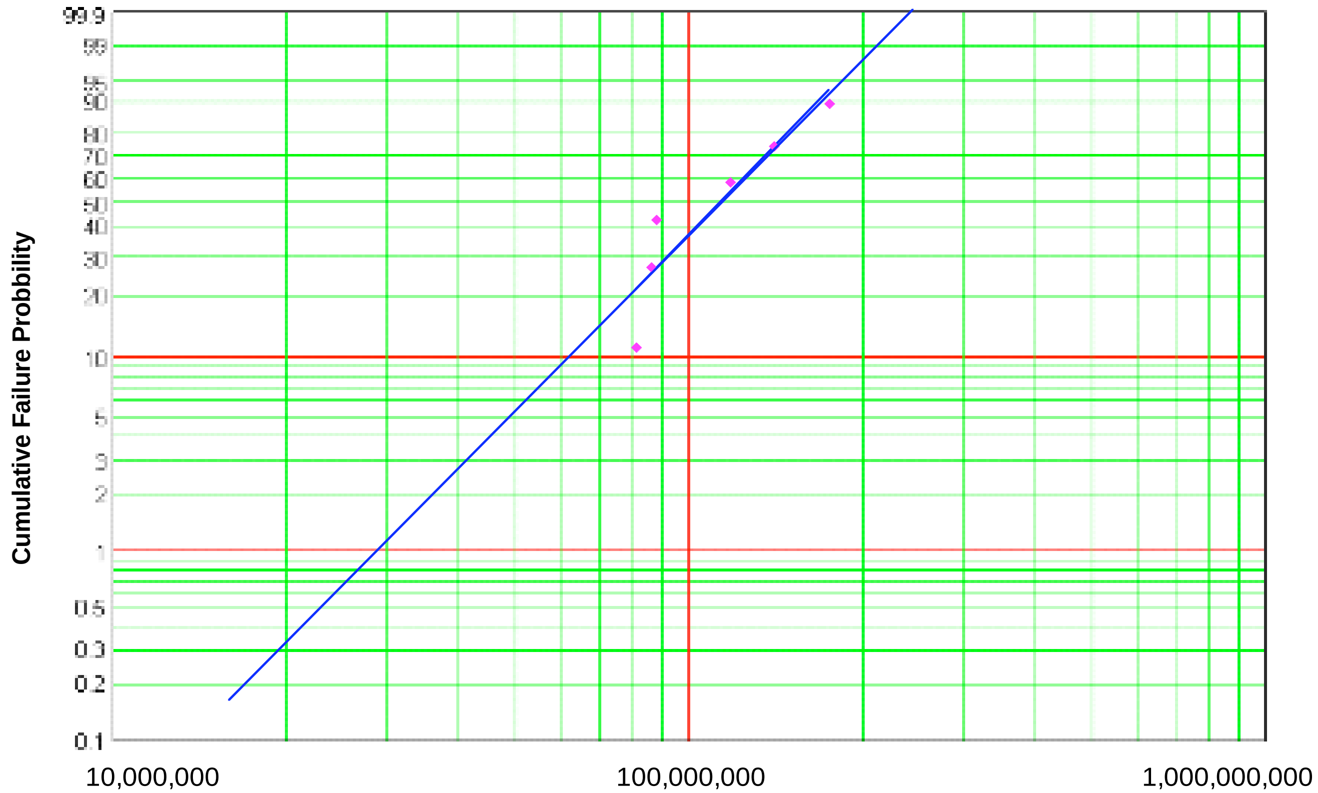


Lifetime Testing of 792 nm LDAs Operating in Long Pulse Mode



Lifetime Testing of 792 nm LDAs Operating in Long Pulse Mode

WeiBull chart generated from the lifetime data

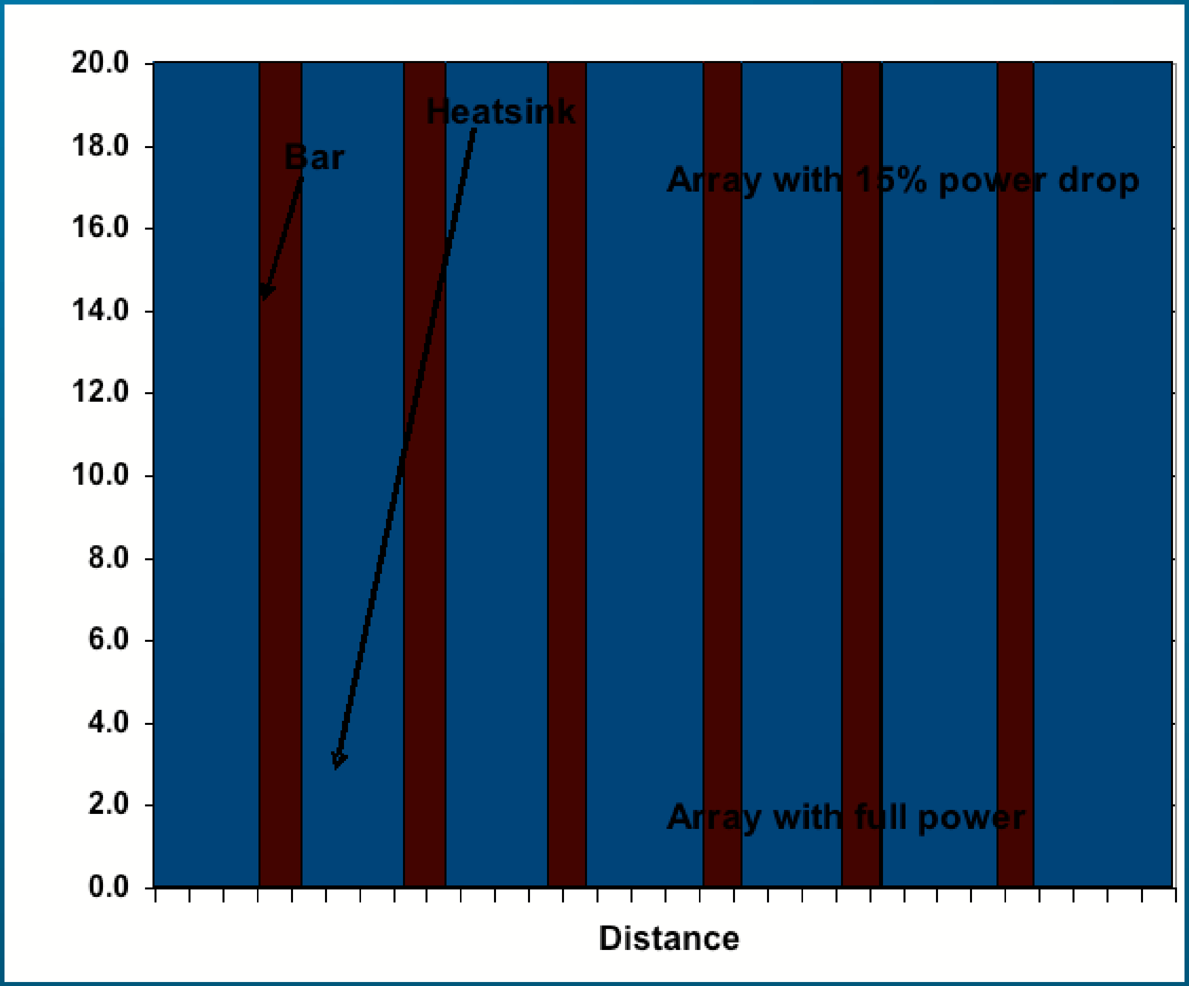


End of the life set at 9% power drop.

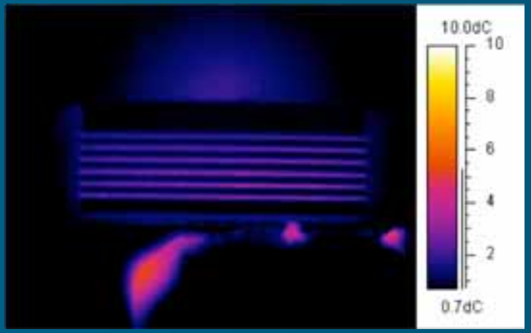
Thermal Measurements

- Measurement of thermal characteristics of LDAs is critical in evaluating different packages and defining optimum operational parameters
- LDA temperature can measured by 3 different techniques
  - IR Imaging: Direct temperature measurement, LDA face temperature map, hot spots (Spatially averaged)
  - Output beam spectral measurement: wavelength shift with temperature (Junction temperature during the pulse)
  - Forward Voltage-Short Pulse Technique (Junction temperature before and after the pulse)

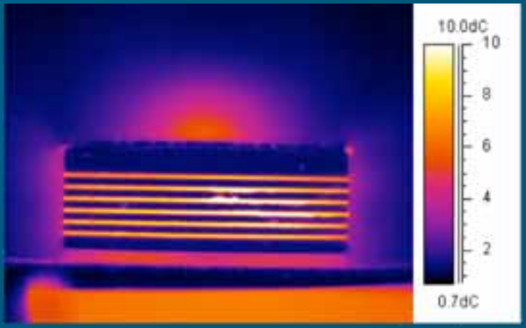
IR Imaging



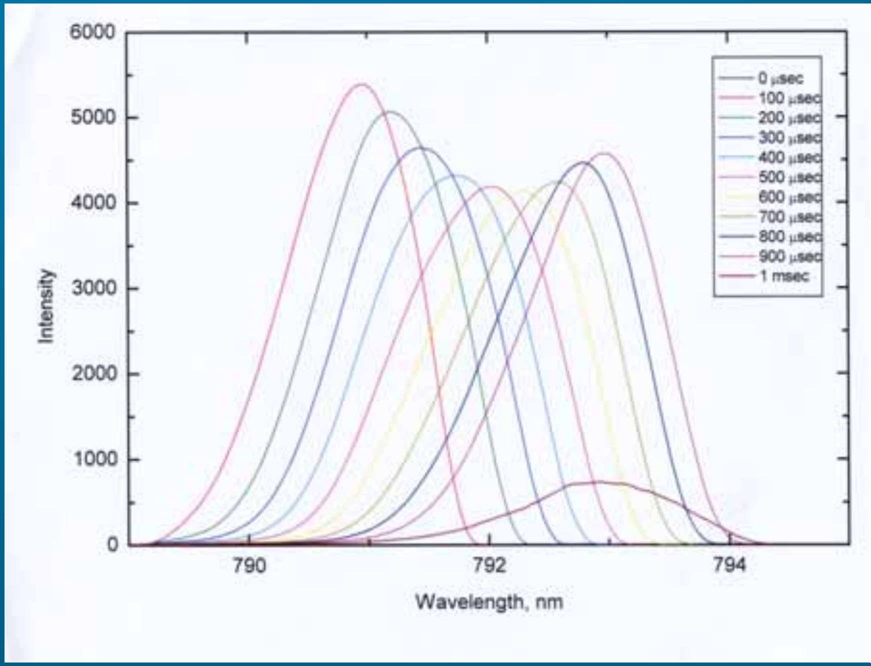
A-6 Array without any dark emitters

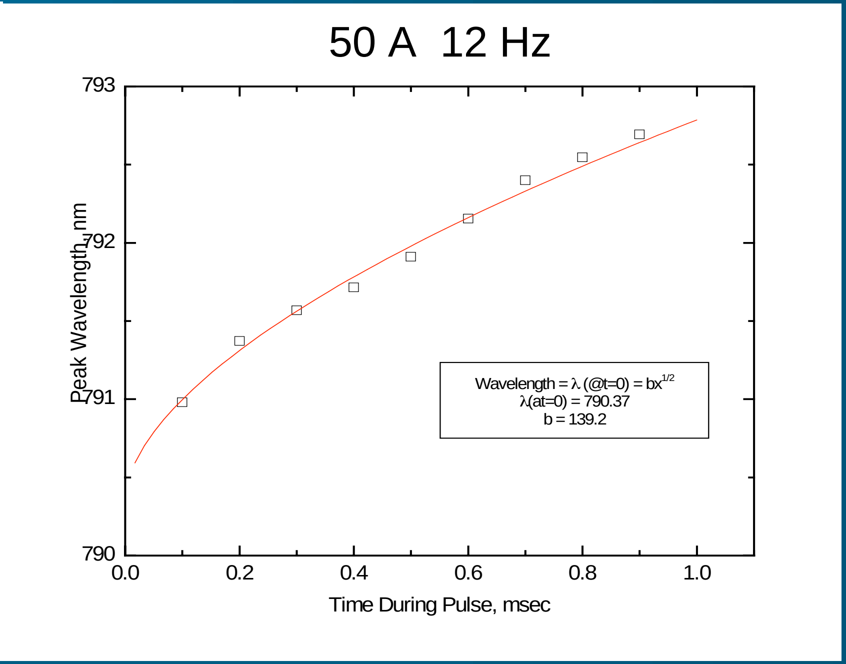


A-6 Array with some failing emitters (15% drop in power)



Temporally Resolved Spectral Measurements

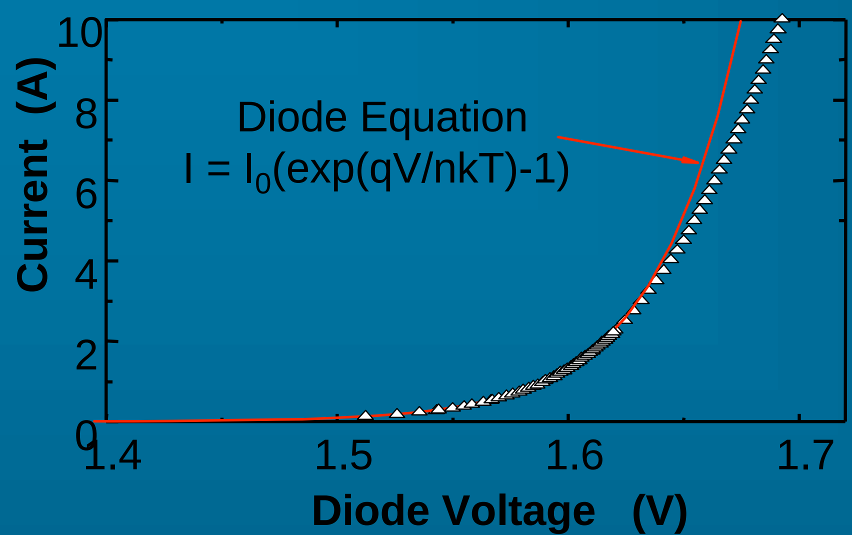




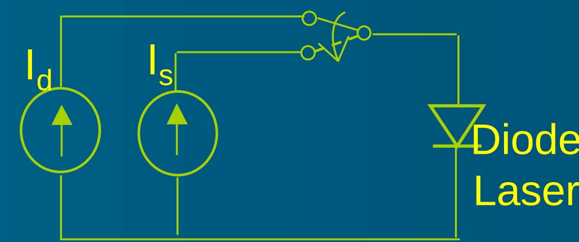
Spectral Shift during Pulse = 2.3 nm

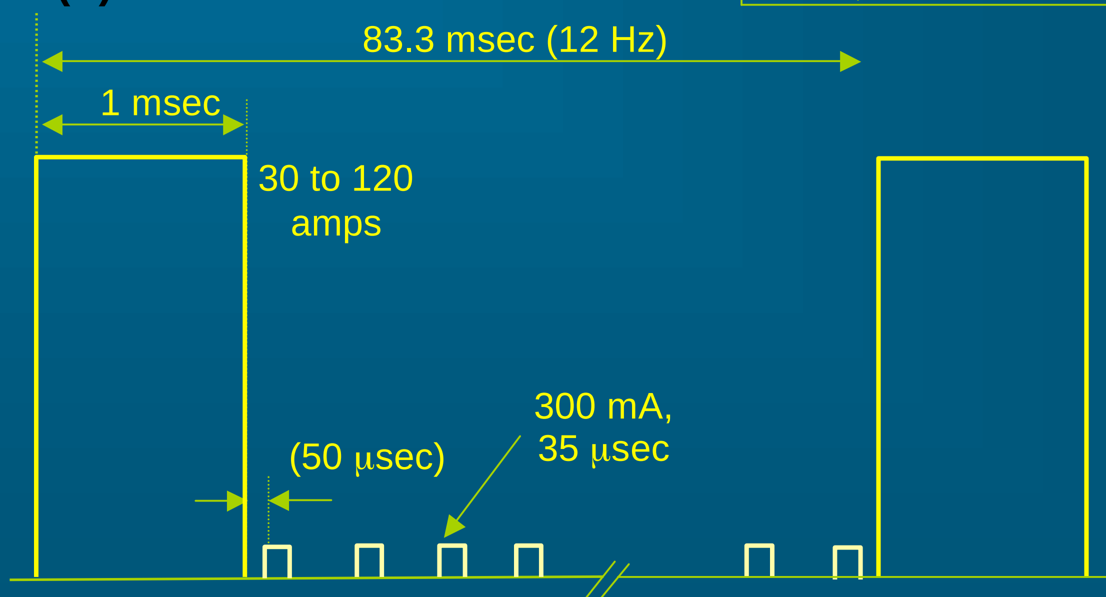
Temperature Rise during Pulse = 2.3 nm / 0.23 nm/°C = 10 °C

Forward Voltage-Short Pulse (Junction Temperature) Measurement



I-V characteristics of LDAs follows classical diode model up to 2.5A





Lifetime Prediction Model

- Arrhenius relationship predicting LDA lifetime

  Lifetime $\propto (T_a - T_b)^{-N} e^{(Ea/kTa)}$

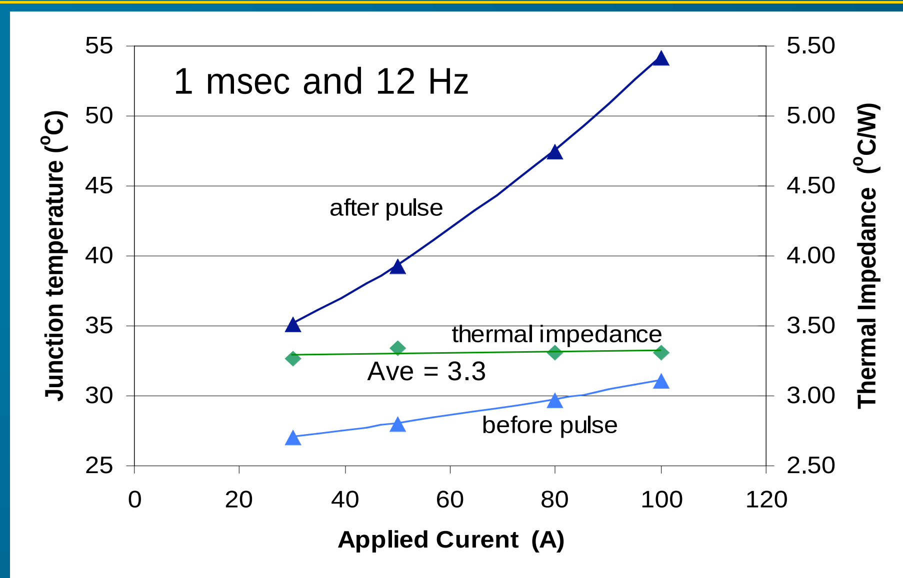
  T_a and T_b are Junction Temperature after and before pulse

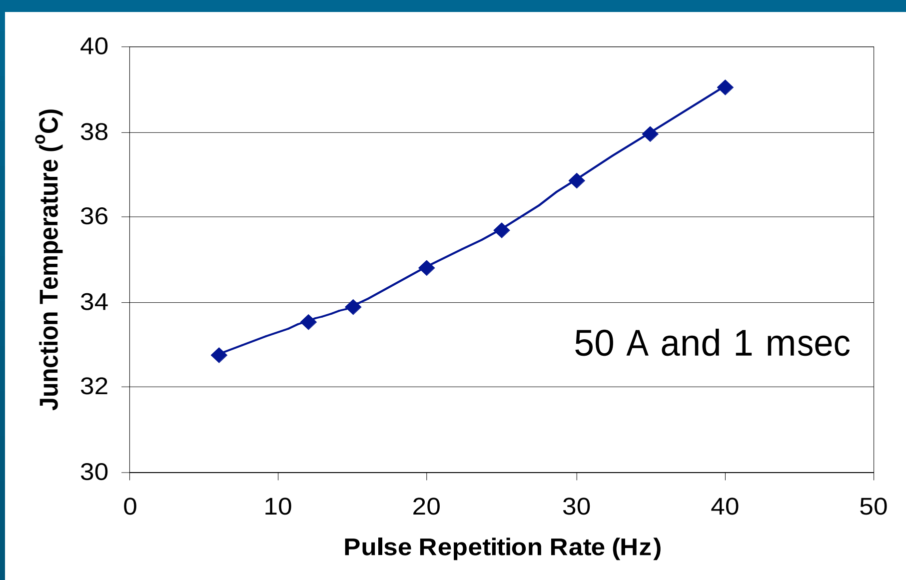
  N is the thermal fatigue constant (2-5)

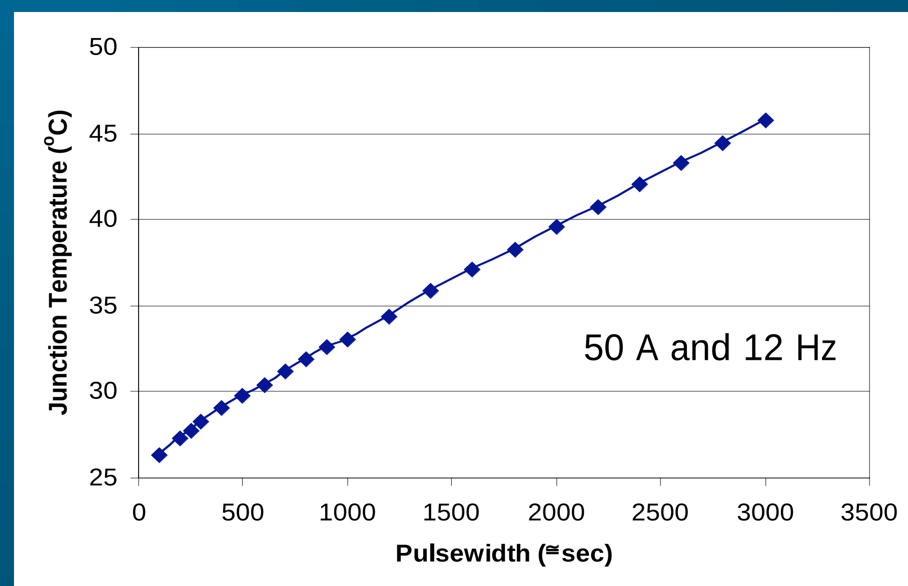
  E_a Activation Energy (0.5-0.9)

- Forward Voltage-Short Pulse measurement technique allows for performing trades for maximum lifetime:
  - ⇨ Peak power (de-rating level)
  - ⇨ Pulsewidth
  - ⇨ Pulse repetition rate

Thermal Characteristics of Quasi-CW Laser Diode Array



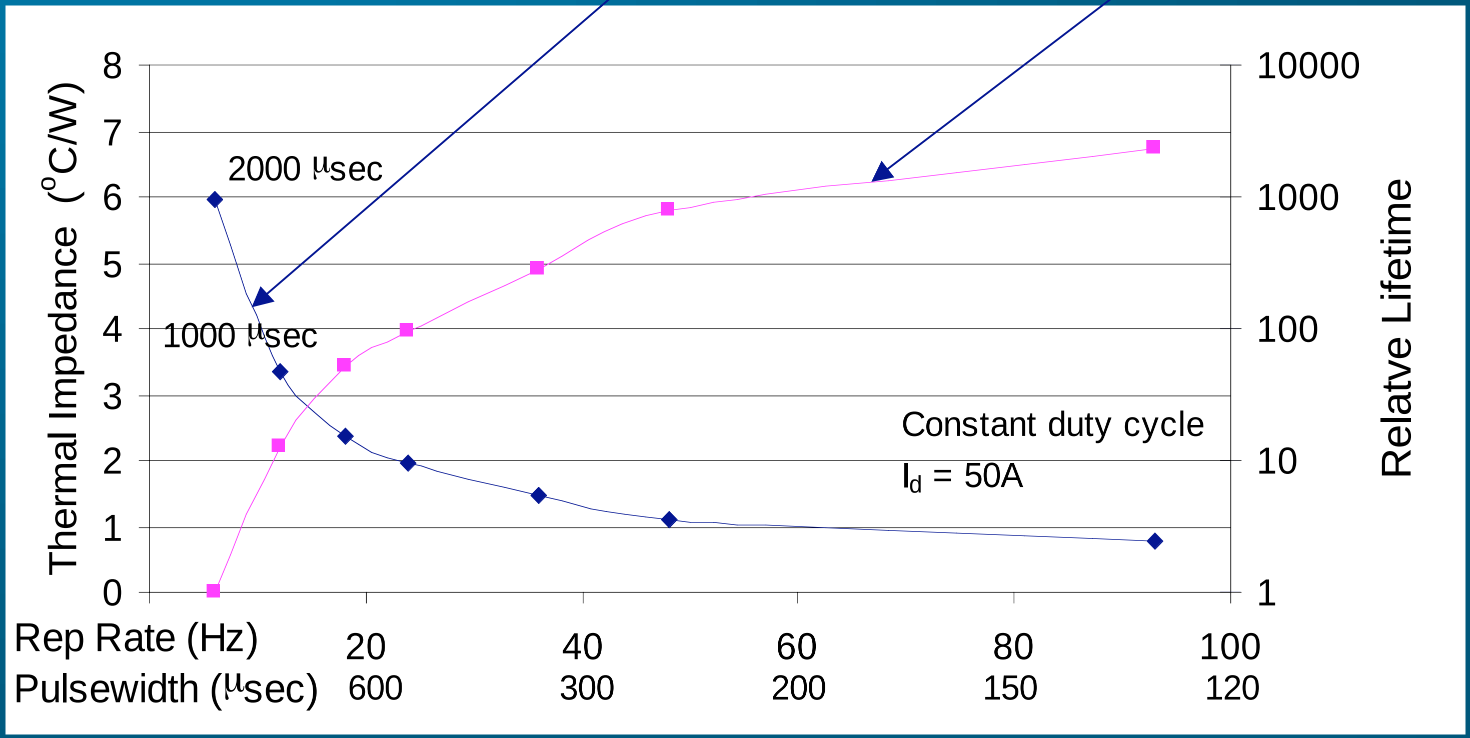




Lifetime Analysis

Package thermal impedance is a function of operational parameters

Operation at 1 msec can reduce lifetime by almost 2 orders of magnitude

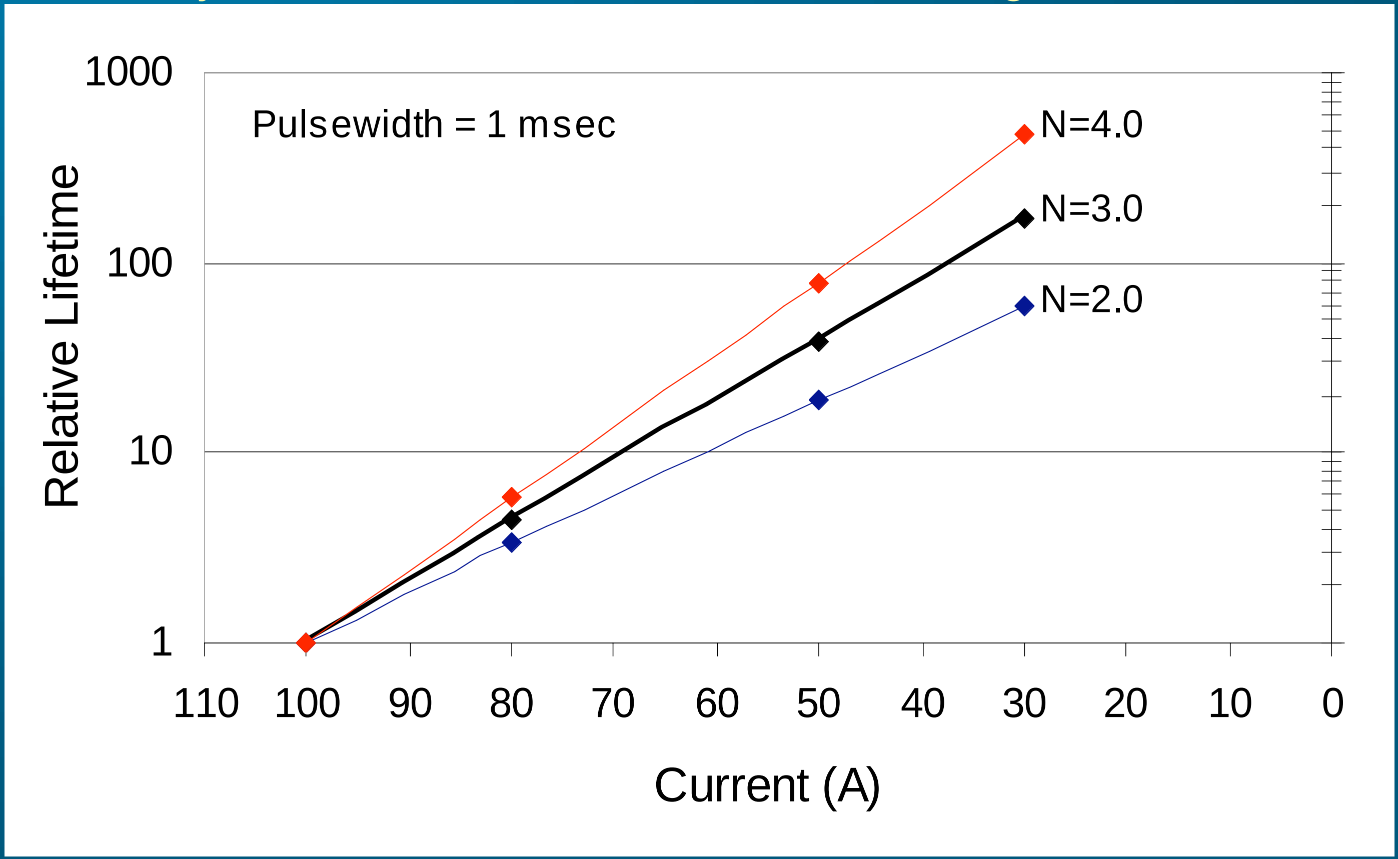


Varying pulsewidth and repetition rate while keeping duty cycle constant at 1.2%. Average output power = 3.4 W.

Lifetime Analysis

Impact of De-Rating

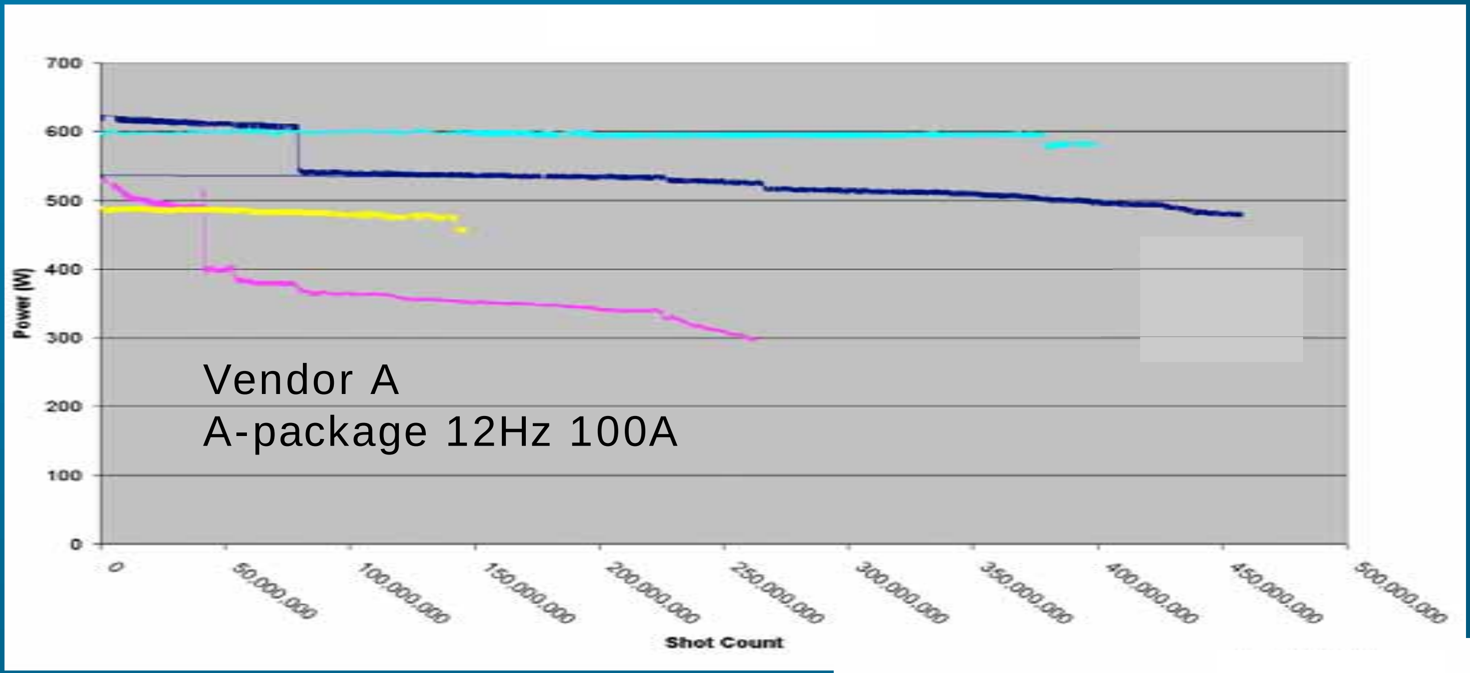
Projected lifetime for different thermal fatigue constant N

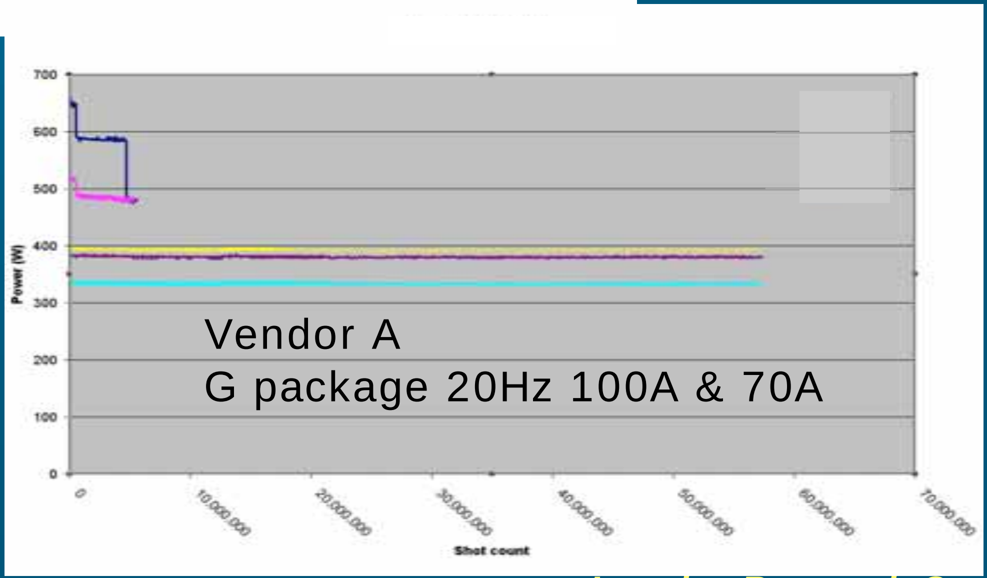


Trade Analysis for Maximizing the Lidar Instrument Lifetime

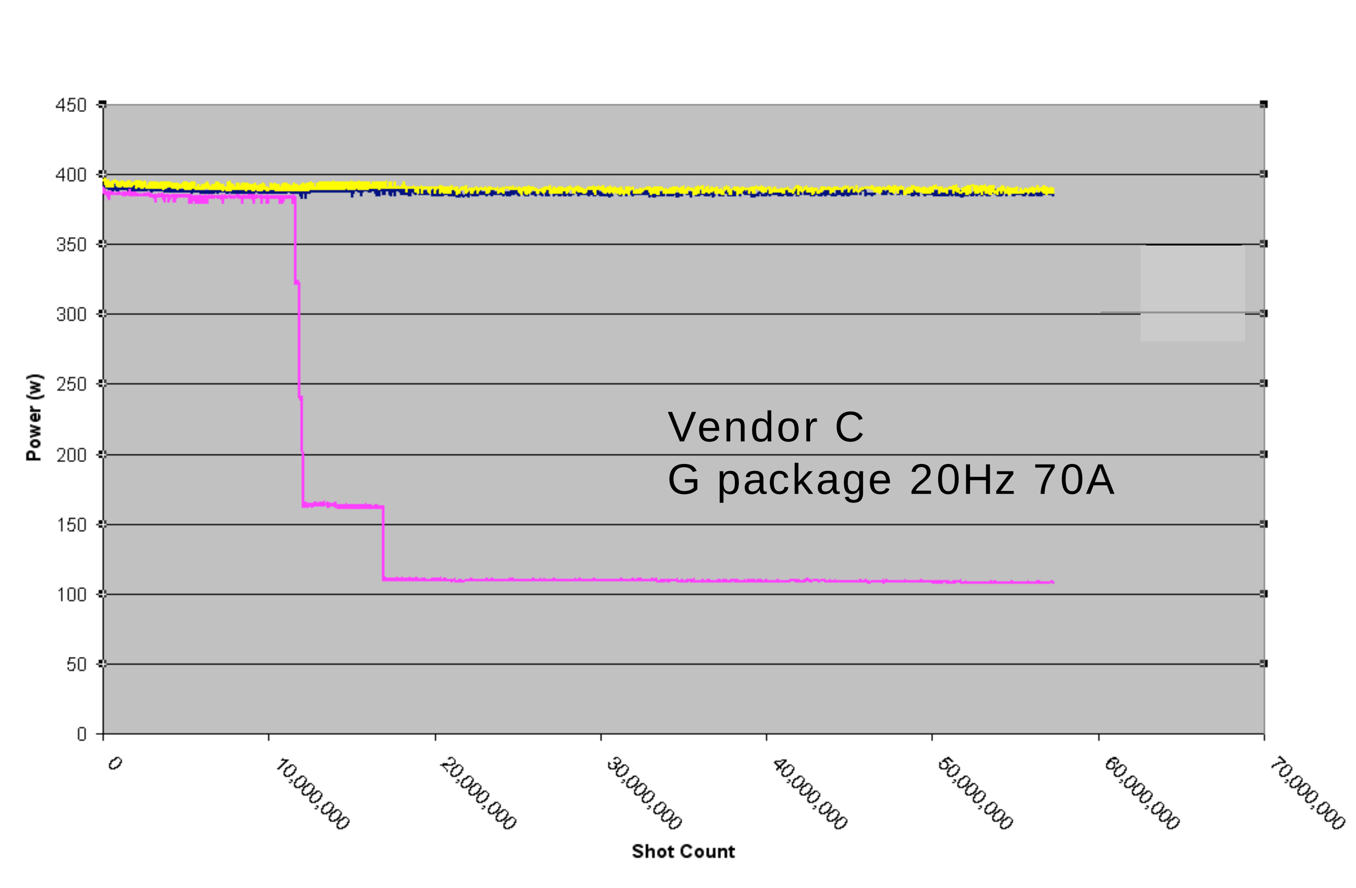
Trade Space	Specifications	Constraints
Array	No. of Bars	Required laser pump power and head configuration
	Pitch	Laser pump brightness requirements
Operational Parameters	Drive Current (de-rating)	Laser pump power requirements
	Pulsewidth	Laser pump power and system efficiency requirements
	Pulse Repetition Rate	Instrument requirements
	Sink Temperature	Platform thermal management system

Lifetime Testing





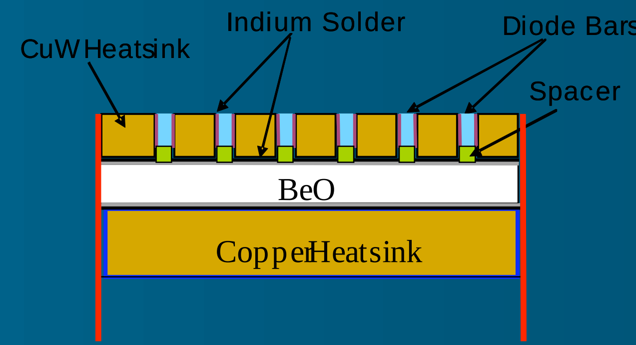
Lifetime Testing



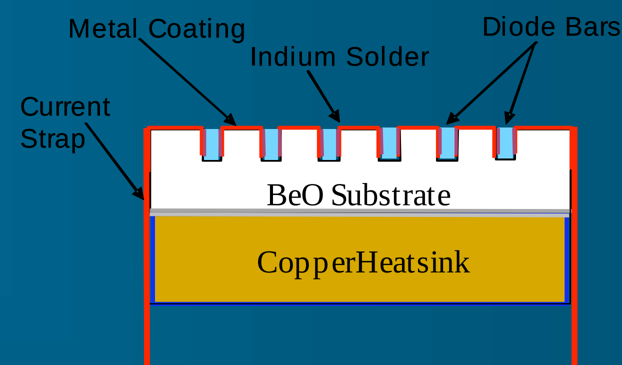
Advanced Materials

Use of advanced materials with high thermal conductivity and matching CTE can improve the array lifetime

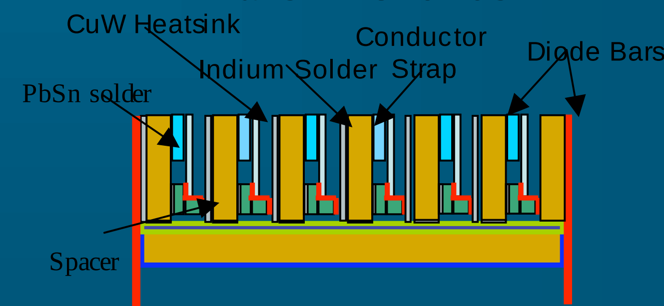
	Material	Coefficient of Thermal Expansion (m/m°C)	Thermal Conductivity (W / m·K)
Standard	GaAs (wafer material)	6.8×10^{-6}	46-55
	Indium Solder	29×10^{-6}	86
	BeO	8×10^{-6}	260
	Copper/CuW	$6 - 8 \times 10^{-6}$	200-250
Advanced	Diamond	1×10^{-6}	1100-1600
	Carbon-Carbon Composites	$1\text{-}6 \times 10^{-6}$	300-600
	Metal Matrix Composites	$6\text{-}16 \times 10^{-6}$	820-890
	AuSn Solder	16	58



Rack & Stack



Bars in Groves

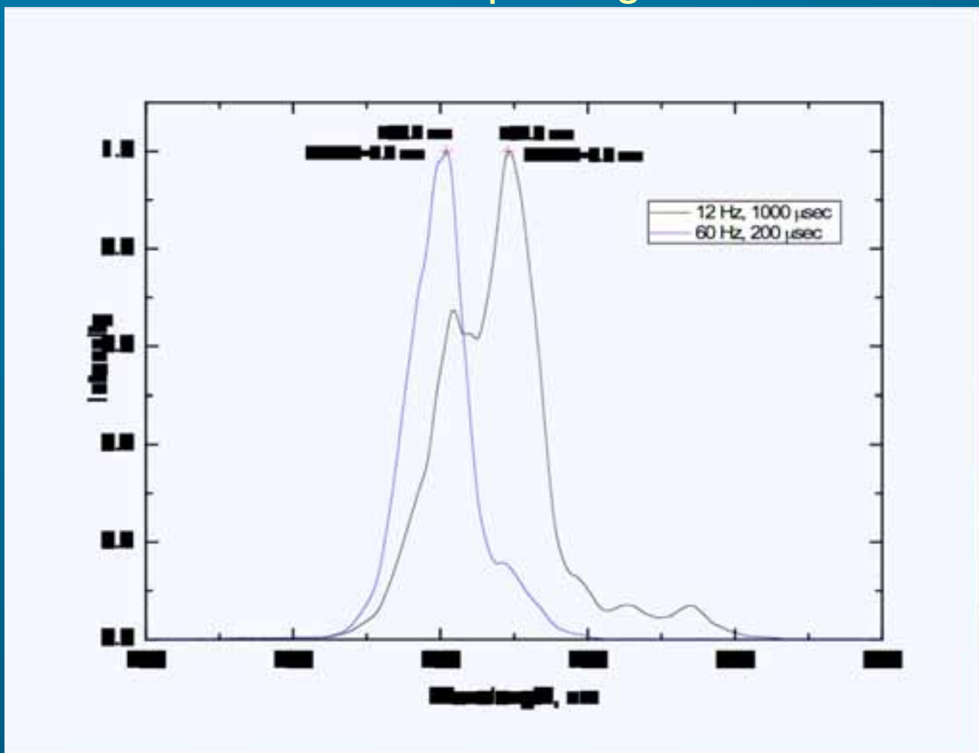


Stacked Subassemblies

Advanced Materials

Standard A-package

Diamond A-package



Spectral response at 200 µsec and 1 msec pulse durations

SUMMARY

- Operation over long pulse duration (~ 1 msec) drastically reduces the lifetime of LDAs
- Lifetime can be improved by:
  - Careful selection of the LDA package type and specification of arrays (number of bars and pitch size)
  - Defining optimum operational parameters for maximum lifetime while meeting the mission objectives (I, t, rep rate, T)
  - Developing new packages by using advanced heat sink materials with high thermal conductivity and matching CTE
- Measurement of Junction Temperature (FV-SP technique) allows for evaluation different packages and defining the optimum operational parameters
- Lifetime testing of different LDAs from different suppliers at a de-rated level operating in long pulse mode is underway